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FINAL REPORT
AN EVALUATION OF ...
... ANTHRACITE ... COAL
FILTRATION ...
MEDIA

Advanced Environmental Research, Inc.

6612 Denny Place
McLean, VA 22101
703-893-4710

FINAL REPORT
AN EVALUATION STUDY:
SAND - ANTHRACITE, MODULAR
FILTRATION UNIT
`SAMFU`

Submitted to:

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September 30, 1986

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER Number 1	2. GOVT ACCESSION NO. ADA173666	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) Final - Phase I Evaluation Study Sand - Anthracite, Modular Filtraction Unit (SAMFU)		5. TYPE OF REPORT & PERIOD COVERED Final Phase I Feasability 4/86 - 9/30/86
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Ronald McIlwain Ronald Barbaro		8. CONTRACT OR GRANT NUMBER(s) DAAK 70-86-C-0033
9. PERFORMING ORGANIZATION NAME AND ADDRESS Advanced Environmental Research 6612 Denny Place McLean, VA 22101		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS 6.2, Applied Research
11. CONTROLLING OFFICE NAME AND ADDRESS Water Technology R&D Team STRBE-FSE Belvoir RD&E Center, Ft Belvoir, VA 22060-5606		12. REPORT DATE October 1986
		13. NUMBER OF PAGES 23
14. MONITORING AGENCY NAME & ADDRESS(If different from Controlling Office)		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for Public Release; Distribution Unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Filtration   Sand - Anthracite Modular Filter
Water Supply - Treatment
Modular Filtration Unit
Multimedia Filter

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

A sand - anthracite, modular filtration unit (SAMFU), was found to successfully reduce solids and turbidity content of raw water feed. SAMFU utilizes media type and size, and relief valves to maximize filtration capacity. It can extend filter run time and reduce mass of units in the field.

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CONCLUSIONS

The data presented within this report supports the following conclusions.

1. The SAMFU has been demonstrated and efficiently removes solids and turbidity from the raw water feed.

2. Fixed media within modules will permit SAMFU use in various spatial orientation and configuration. This holds promise for reduction of space requirements, or at least better utilization of available space in future ROWPU's.

3. Additional effort is required to develop SAMFU potential for:

    a) Full use of media capacity by striking balance between operating pressures, media sizing, capacity and raw water particle sizes.

    b) External filtration runs via 3a above, or the use of valves to effectively remove clogged modules from service.

4. Anthracite is an effective alternative for some sand media which holds promise for weight reduction.

5. Screens, without media, will capture suspended solids and hold promise of use as a prescreen "media" of minimum mass.

6. Full use of filtration media depth is indicated as feasible and holds promise for extension of filter run time. This compromise between capacity and volume requirement; pressure and media size requires much better definition.

7. Screens if properly matched to media size, hold promise for use to hold the media in a fixed position within the modules. Additional work is needed to identify sources, materials, and to match media to screen mesh for smaller particle sizes.

8. Use of properly sized screens to hold media will minimize, possibly eliminate media loss in either filtration or backwash mode. Work is needed to affect "in situ" backwash of the modules.

9. Release pressures for by-pass valves were not reached in this preliminary study. This desirable feature remains to be established and studied.

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I. **INTRODUCTION**

The U.S. Army Belvior Research and Development and Engineering Center, BRDEC, is engaged in a program to further develop its highly successful Reverse Osmosis Water Purification Unit (ROWPU). This unit, shown in figure 1, consists essentially of raw water filtration to remove the suspended solids, followed by reverse osmosis to extract purified water and disinfection by post chlorination. The BRDEC program includes efforts to:

(A) Minimize unit volume and mass.
(B) Simplify and minimize unit operation and maintenance procedures.
(C) Increase unit production and efficiency; especially when raw water supplies are highly turbid with colloidal solids.

Under Contract Number DAAK70-86-C-0033 Advanced Environmental Research Inc. (AERINC), a minority owned, Mclean Virginia based corporation, has designed, developed and tested a Sand-Anthracite Modular Filtration Unit (SAMFU) which will, with development, help meet all the program objectives and provide flexibility needed to meet specific field conditions or requirements.

The SAMFU employs 3 to 4 inch deep beds of variously sized anthracite, which has a lower specific gravity (1.3 vs. 2.65) than sand. It is held in place within a 1.25 foot square "module" by appropriately sized plastic screens. Solids removal is accomplished by filtration of raw water through the variously sized media hopefully utilizing the full depth and capacity of the media. A pressure relief valve centrally located in each module provides a by-pass mechanism for any module which becomes clogged. Thus by stacking the several modules (each with its specifically designed media type, size and depth), conventional clogging problems can be circumvented and run times extended. Figure 2 shows an intact complete module,(2A), and the same module with cover plate removed,(2B). Figure 3 shows the stacked modules within their Module Housing (MH);and figure 4 shows the 'closed' SAMFU ready for operation.

The 16.0" x 16.0" x 48.0" tall unit can be operated in up or down flow mode, by simply inverting the unit in place. It is intended to be used in conjunction with a second similar unit to eliminate down time for backwash. Modules are sealed in place and designed to contain media and allow for 15% media expansion for in-situ backwashing. Modules are currently removed for backwash by hose pressure. The anthracite media has a specific gravity approximately 1/2 that of sand, which will reduce filter weight to the extent it replaces sand.

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FIGURE 1
600 GPH ROWPU

BASIC FLOW SHEET

FIGURE 2a
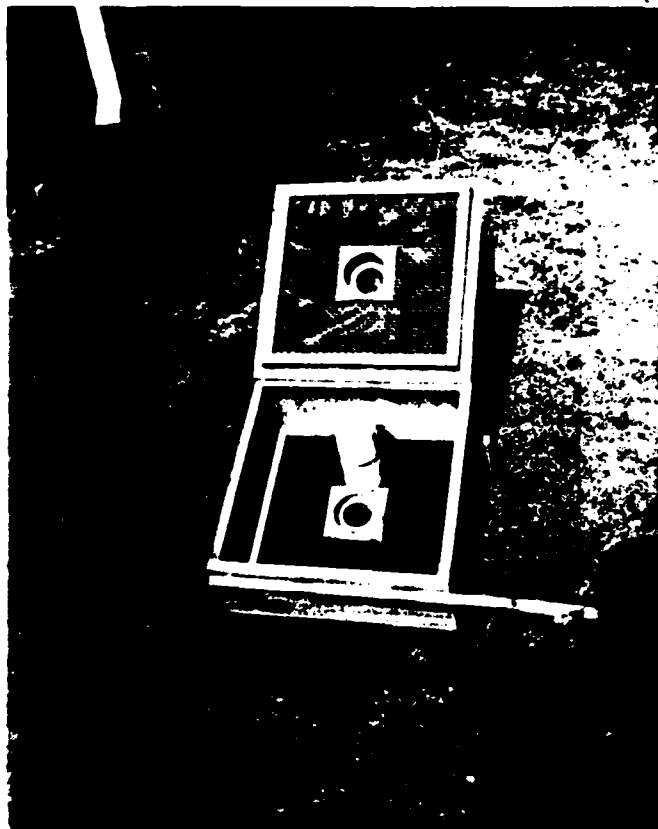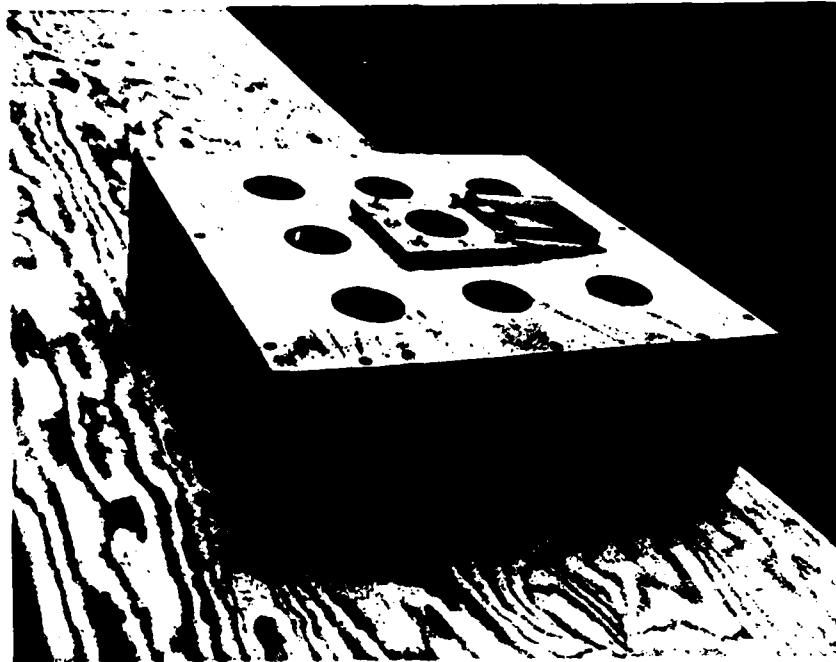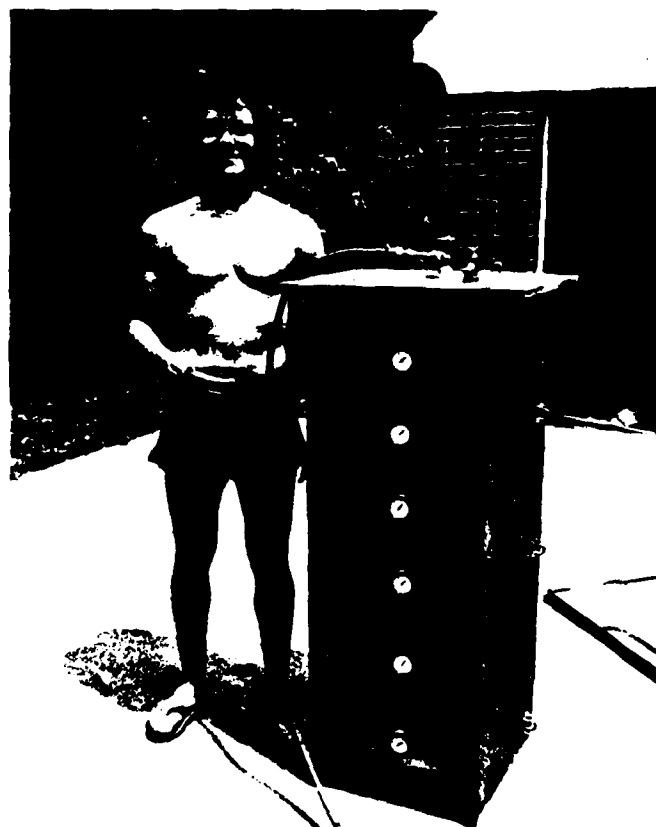
MODULE

FIGURE 2b

MODULE:
    INTERIOR
    NO MEDIA
    NO SEALS

FIGURE 3

UNTREATED MODULES IN HOUSING

FIGURE 4

SAMFU

AERINC's testing program had the following objectives:

A) Determine feasibility of using screens to prevent media loss during filtration and backwash

B) Determine the feasibility of using shallow depth, modular anthracite filters for solids removal

C) Determine the feasibility of using valves to by-pass modules ,based on pressure sensed

The project was directed by Dr. Ronald D. Barbaro, and conducted by Messrs Ronald McIlwain, Ronald S. Barbaro and Steven Cawthron. The project Engineer for the BRDEC, was Mr. Donald Lindsten (STRBE-FS).

The SAMFU was successfully demonstrated on August 19,1986 at AERINC facilities at 6612 Denny Place, McLean Virginia.

This report describes the SAMFU; presents summarized test results and discussion thereof; concludes that the SAMFU is a feasible concept and makes recommendations for further development of the concept.

II. DESCRIPTION

This section describes the modules and their container or "Module Housing" (MH), as well as the SAMFU they comprise. It includes also, module by-pass valves, Raw water feed, Raw water feed systems and the demonstration or test system which is the composite of all the above,and the SAMFU. Design/construction criteria or goals, are presented together with the avenue pursued to their achievement. the dimensions and figures presented afford a degree of familiarity with the appearance, function and problems associated with the unit. These units are preliminary test models and represent prototypes in only the broadest interpretation of the word.

A. MODULE

In order to test the modular filter concept, an experimental 'module' had to be designed which would meet certain minimum criteria including:

1. <u>Resist external by-passing of the module during filtration and backwash modes.</u>

   A module was constructed with 0.875" thick hardboard sides and 0.5" thick plywood top and bottom. Once fastened together, this box formed a rigid shape allowing gaskets to be placed between the module and pressure vessel to prevent external by-pass of the module. The external dimensions of all modules are 15 x 15 inches with an internal dimension of 13.25 x 13.25 inches or 1.22 sqft. This area is reduced to 1.11 sqft effective due to placement of a by-pass valve and brace. The depth varied between modules and will be discussed later. See figure 5.

2. <u>Resist internal short circuiting and by-passing during filtration and backwash modes.</u>

   To prevent short circuiting, nine equally spaced 1.75 inch holes were made in both the top and bottom of each module. The center hole of each module became the location of the module by-pass valve, and the valve inlet was covered with an aluminum baffle to prevent premature opening of the module by-pass valve as shown in figure 6. Neoprene gaskets placed above and below each valve minimized internal by-pass of the filter media. See figure 7.

3. <u>Allow placement of the module by-pass valve in order to allow by-passing of the module if the media surface or depth exceeds loss of head criteria.</u>

   The module by-pass valve was situated in the center of each module in order to minimize short circuiting once the valve opened. To hold the valve in place, braces were fabricated from 4 x 4 x 0.5 inch plywood by creating a sleeve on the bottom and top of each module, into which the valve fit. A top plate was fastened down to hold the valve firmly in place. See figure 8.

FIGURE 5
BY-PASS-VALVE
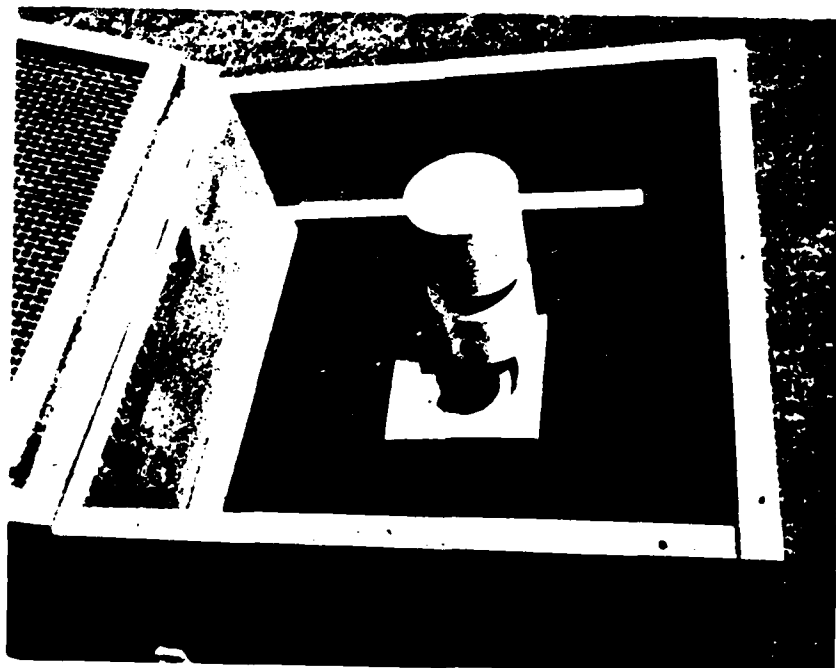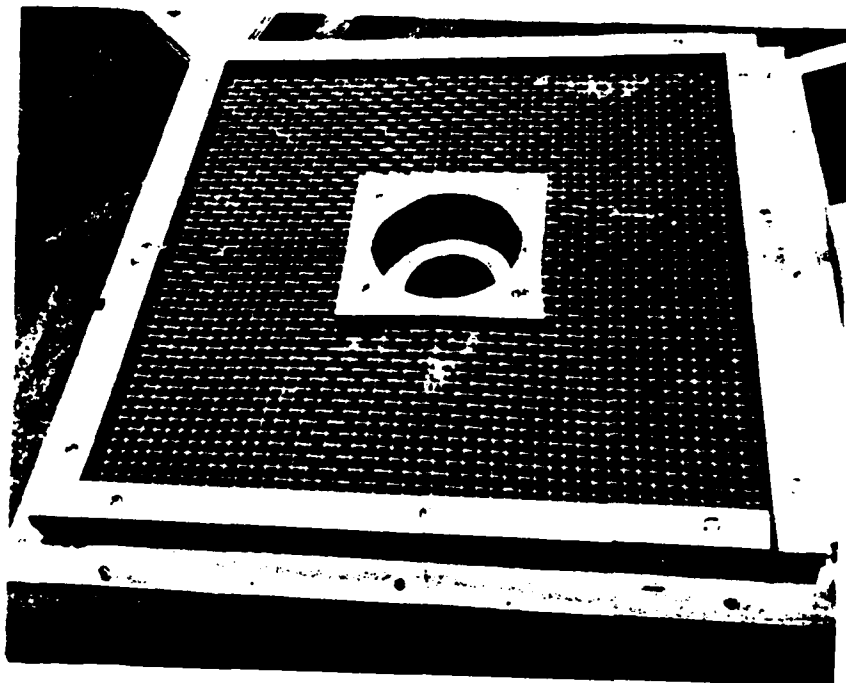
FIGURE 6
VALVE COVER

FIGURE 7
VALVE
SEAL

FIGURE 8
VALVE + BRACE

4. <u>Support and hold screens in place and retain media during filtration and backwash modes, without reducing the flow rate through the unit.</u>

Media support screens were held in place in the center of each module by the valve braces, and by screen support strips around the inside perimeter of each module. In both of these cases, the screens were sandwiched between upper and lower 'brace' strips as shown in figure 9. The lower strip served to hold the screens away from the bottom of the module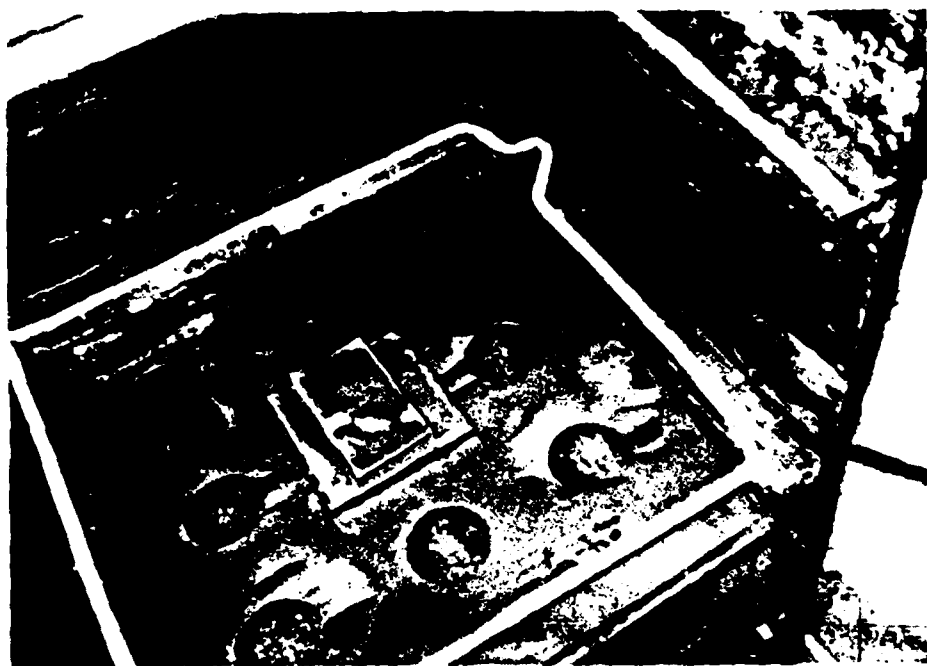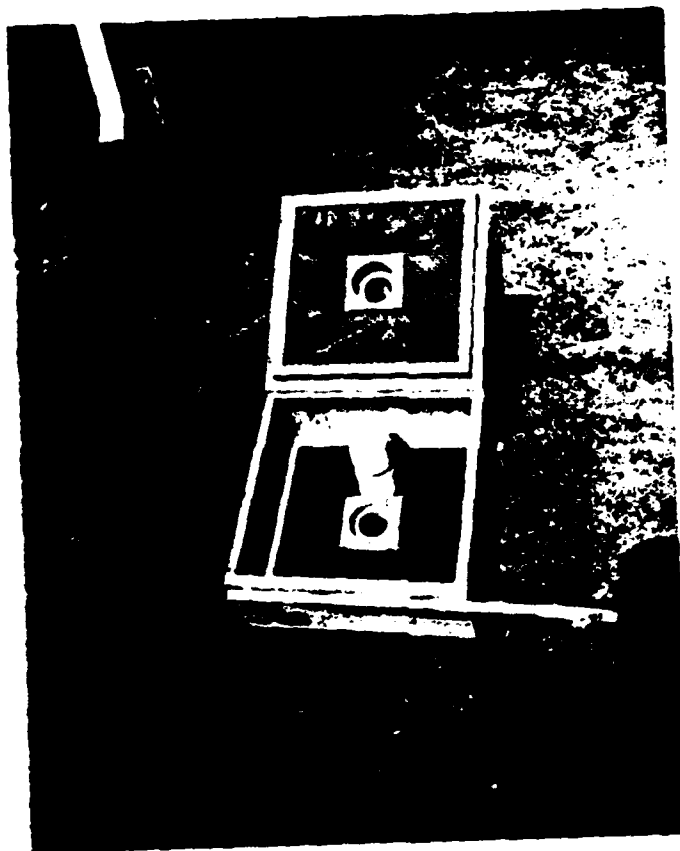 to insure an adequate liquid velocity through the unit. The upper strip held the screen firmly in place by pressing it against the lower brace strip. Screen support strips were constructed of 0.375 x 0.5 inch hardwood , strips fastened with wood screws. The valve braces are those used to secure the valve in place as described above.

The size screens located within each module were chosen based upon the size media to be placed in that module. Exact sizes of screens and media are described later in this report. A support screen was placed directly beneath each finer mesh screen to add rigidity and strength.

5. <u>Provide adequate depth and surface area of media for experimental purposes.</u>

A) Module surface area was made square in order to simplify the design of its housing (MH). The actual size chosen provides approximately 1.11 sqft of surface area.

B) Media depth ranged from zero to six (6) inches of anthracite or sand.

Although not design criteria, several other factors were taken into consideration during the modules fabrication, including:

A) Glues, caulks, and other permanent construction techniques were avoided so that modifications and adjustments could be made to the modules as necessary.

B) Readily available and easily workable construction materials were utilized where possible so that modifications and adjustments could be made to the module as necessary.

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FIGURE 9

SCREE BRACE STRIPS

B. MODULE HOUSING

A containing vessel or module housing (MH) was constructed to hold the modules in place, one above the other; and facilitate evaluation of the modular concept applied to solids removal. For purposes of budget and adaptability, the unit was constructed of 0.75" exterior grade plywood, coated with Cuprinol brand wood preservative to prevent delamination. All joints were grooved and glued and sealed with silicone sealant to ensure integrity. The dimensions of the MH holds six modules snugly. The overall dimensions of the MH were 16" x 16" x 48" tall. The sides of the MH extended beyond its back to provide protection for all instrumentation associated with the box. The front panel of the MH, was removable for access to the modules.

The MH had to meet the following criteria:

1. <u>Provide</u> <u>support</u> <u>and</u> <u>proper</u> <u>placement</u> <u>of</u> <u>the</u> <u>modules</u>

To hold modules in place, regardless of the orientation of the MH, appropriate lengths of 1" x 0.5" pine strips were affixed to three interior walls of the MH with screws and coated with Cuprinol preservative. The strips were placed above and below each module, providing a "slot" into which each module fit, and a space of approximately 1.5" between each module. A fourth, removable wall, or door, had no pine strips, its interior surface was covered with a 2' x 4' x 1" thick rubber mat, which sealed the forth side of the module. Figure 10 shows the dimensions of the box used in this project.

2. <u>Monitor</u> <u>pressure</u> <u>at</u> <u>locations</u> <u>above</u> <u>and</u> <u>below</u> <u>each</u> <u>module.</u>

To monitor pressures at and across each module, 30 psi gages were installed into the 1.5" space above and below each module, through the rear wall of the MH. The recessed rear wall and extension of the sides, top and bottom of the MH, provided protection for the protruding gages, as shown in figure 11.

3. <u>Provide</u> <u>access</u> <u>for</u> <u>in</u> <u>place</u> <u>for</u> <u>inspection</u> <u>of</u> <u>modules</u>

To provide the ability to observe the modules in-situ after a test, the entire front of the vessel was removable and did not disturb the modules when removed. This not only allowed inspection of the modules, but also provided access thereto.
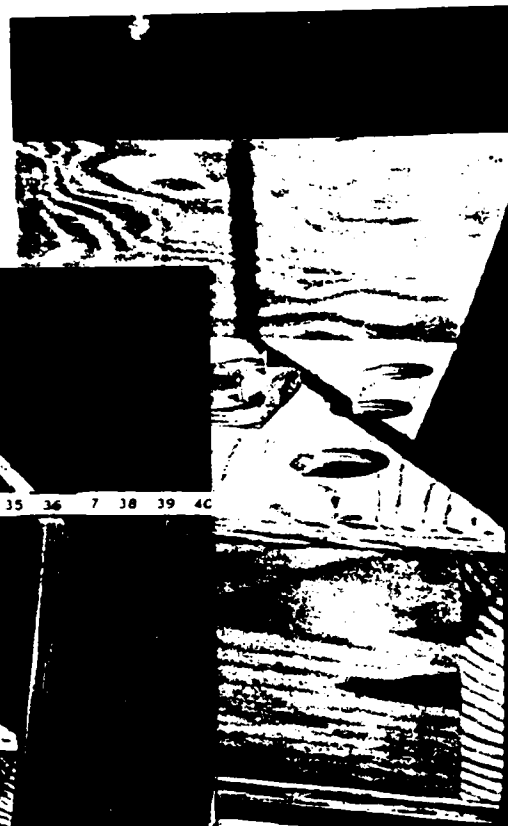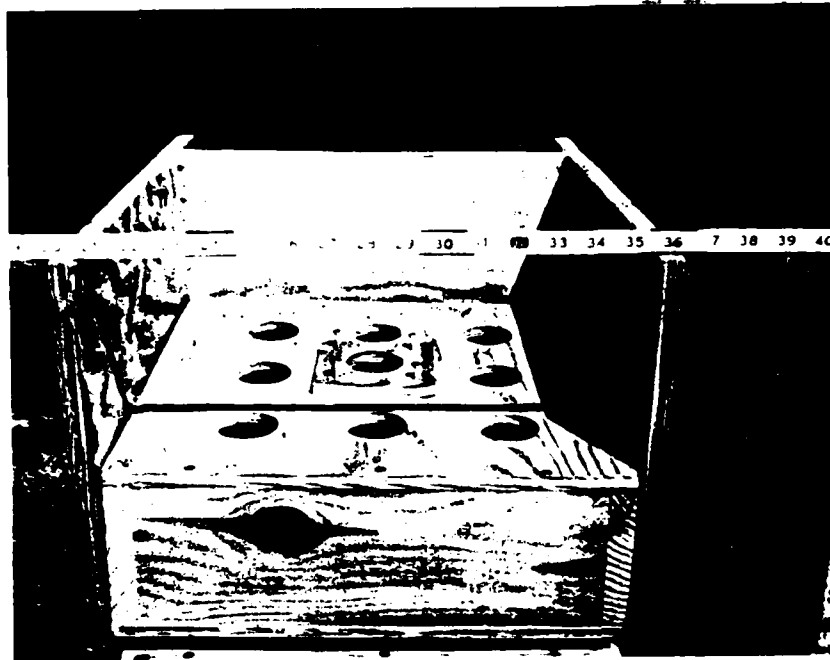
FIGURE 10
PERSPECTIVE

FIGURE 11
PRESSURE GAUGES

4. Allow attachment of feed and drain lines and release trapped air.

   To attach influent and effluent lines to the MH, 0.5" plumbing fixtures with 0.625" hose connections were installed through the top and bottom.

   To release trapped air from the box, a 0.5" manual relief valve was installed through the top of the MH.

   C. VALVES

1. Module By-Pass Valves

   These valves are centrally located in each module, and function to by-pass that module if either media,surface or depth exceeds head loss criteria. These 2" polypropelene, in line, pressure relief valves are manufactured by King Brothers Inc. The valves were rated to release at 4.0 psig pressure differential.

2. Pressure Relief Valve

   A 0.5" petcock type relief valve was installed through the top of the box, to allow escape of trapped air during start up of filtration operations. The valve is manually operated.

   D. THE SAND ANTHRACITE MODULAR FILTRATION UNIT (SAMFU test model).

   This preliminary SAMFU model is a watertight combination of six modules and MH, designed to test the feasibility of the modular concept. As such the following criteria were met.

1. Provide watertight seal at valve and between the box wall and each module to prevent by-pass of modules.

   Creation of watertight seals at the valves was accomplished by placement of hard rubber gaskets around top and bottom of the module by-pass valve chamber as shown in figure 7. Obtaining proper seal between the MH and each module presented significant problem and delay in "loading" the modules into the MH. Attempts to use 0.5" rubber strips (gaskets) around three edges of the top and bottom of the module, (between module and supporting pine strips), failed due to fatigue. Neoprene rubber tubing was stretched around the periphery of the module prior to insertion into the box, effectively sealed three sides of the module.

The interior surface of the fourth side, or door, was covered with a 2' x 4' x 1" thick rubber mat which sealed tightly against the modules, pine support strips and edge of the box. This seal was secured by nine 0.375" x 5.0" attachment bolts and reinforced appropriate lengths of 0.125" x 1.5" steel flat bars in line with the bolts. In addition a wood and steel (0.625" allthread) "vise" which drew the door to the MH. See figure 12.

2. <u>Permit observation of modules in place, after each test run.</u>

The removable door permitted observation of the modules and access thereto for maintenance and modification.

3. <u>Provide proper combination of screens and media to achieve acceptable level of turbidity reduction while operating at hydraulic loading of approximately 4.0 gal/min/sqft.</u>

The nature and arrangement of modules in the SAMFU is determined by the direction of the flow through the unit and function to be performed, eg. quantity and size of particles to be removed. Initial combinations of screens and media in each module, and and of the several modules within the MH, included use of 0.25" wire support screens, 1 mm pore agricultural screen, fine (<1 mm) sand and several sizes of anthracite. Several module configurations were tested and that used in the demonstration model is shown in Table AA.

TABLE AA

MODULE	SCREENS*		MEDIA		
NUMBER	TOP** (Inches)	BOTTOM**	DEPTH	EFF. SIZE (mm)	UC***
1 (top)	0.125	0.0625	none	–	–
2	0.0625	0.0180	4" lg	1.0 - 1.2	1.4
3	0.018	0.018	4" fine	0.6 - 0.8	1.7
4	0.018	0.018	4" fine	0.6 - 0.8	1.7
5	0.018	0.018	4" sand		
6 (bottom)	0.018	0.018	4" sand		

    * all support screens were 0.125" mesh polypropelene
   ** mesh size as shown
  *** uniformity coefficient

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FIGURE 12

MODULE HOUSING BRACES

Media depth varied from zero to six inches of anthracite or sand. All media was prewashed in sieves of appropriate mesh prior to being placed in the modules in order to remove fines and dust. Anthracite was used as much as possible to minimize total SAMFU weight.

E. The Raw Water Feed System

This system was used to prepare raw water feed by diluting a measured quantity of raw feed "concentrate". A drill operated pump was used to transfer one (1) gal of the "concentrate" to one of several "dilution drums" containing 30 gallons of tap water. Mixing was accomplished by a variable speed paddle mixers affixed to the concentrate and dilution drums. The diluted feed was pumped from dilution drums (35 gal) to the SAMFU via a 1/16th HP submersible sump pump and 5/8" hose. A six foot length of 5/8" hose was connected to the bottom of the SAMFU drained the MII and facilitated sampling. This system is shown in figure 13.

While the contents of one "diluted feed" drum was being pumped to the SAMFU, another was being prepared from "concentrate" and tap water. In this way batch feed produced essentially uninterrupted (semicontinuous) and constant flow.

F. Raw Water Feed

Direct withdrawl from highly turbid flowing streams would have provided more "characteristic" influent to the SAMFU, but was both logistically and economically unsound. Characteristic "colloidal" content was therefore sacrificed for the controllable availability and turbidity of a synthetic feed.

Approximately 10.0 pounds (4540g) of bottom mud from a quiescent zone of the far headwaters of Goose Creek at route 734 in Loudon County Va., was screened (1.6 mm mesh), and mixed with 20 gallons of domestic tap water, to form our "feed concentrate". This "concentrate" was pumped to the SAMFU either directly, or at various dilutions, in either batch or "semicontinuous" flow modes. In the demonstration test, one (1) gal concentrate was mixed with 30 gals of tap water to form the "diluted feed".

Turbidity was measured on each raw water batch fed to the SAMFU, and was used as a measure of unit performance. Feed water turbidity values ranged from 130 to 180 NTU's. Values for the composite raw water feed sample used in the "demonstration" was 130 NTU. All drums were 35 gal units measuring 4' high with a diameter of 24". They were thoroughly scraped and washed prior to use.

STREAM BOTTOM MUD

SCREEN TO REMOVE DEBRIS

TAP

FEED CONCENTRATE

TO SAMFU
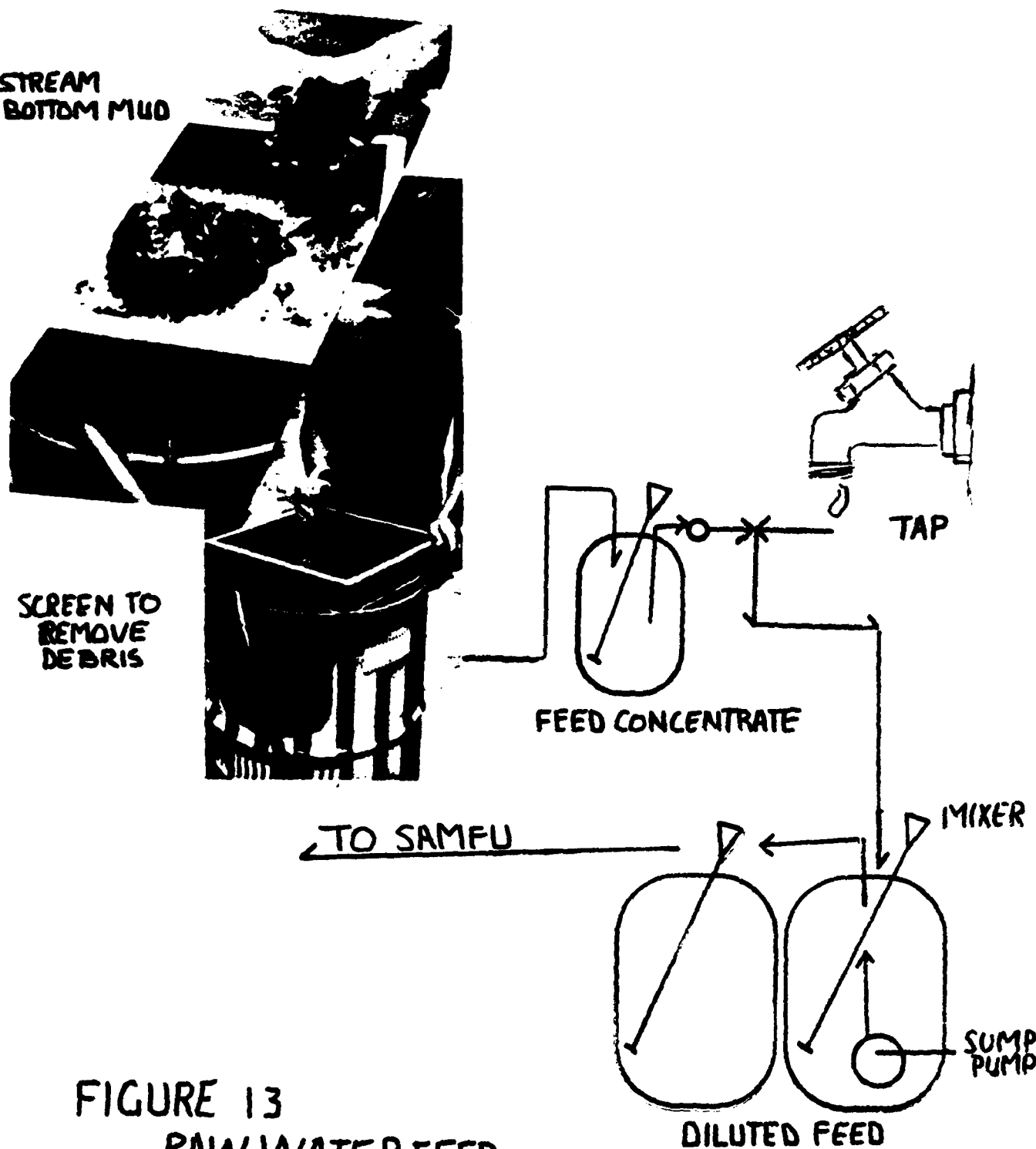
MIXER

DILUTED FEED

SUMP PUMP

FIGURE 13
RAW WATER FEED

FIGURE 14
THE TEST SYSTEM

SAMFU
AND
Feed System

G. The Demonstration '(test)' System

This system consists of the combination of equipment needed to mix and feed raw water to the SAMFU, and the SAMFU model itself. Each component of this system is described above, and the combination is shown in figure 14, and the entire system met the following criteria:

1. **Deliver a "continuous" flow to the SAMFU at a constant rate.**

   The feed system described above met this criteria in a crude but adequate manner. Minor indiscernable flow interruptions occurred when the sump pump was transferred from one feed drum to the next.

2. **Provide raw water of consistent turbidity.**

   The drill operated pump was found to deliver "feed concentrate" at a consistent rate of one (1) GPM. The drill pump was operated for a period of time needed to deliver the appropriate quantity of "feed concentrate" to prepare the "diluted feed".

3. **Provide access to raw water feed and product water for sampling purposes.**

   Tops to the 35 gal drums used for the raw water feed were removed so they could be readily sampled. Product water from the SAMFU passed through a 6 foot length of 5/8" hose which allowed ready access. Discharge from this hose was routinely passed through 0.018" mesh screen, except when being sampled.

4. **Permit gases trapped in the modules to escape.**

   The 0.5" petcock valve installed through the top of the SAMFU met this criteria.

5. **Avoid raw water by-pass of modules except via module by-pass valves.**

   This criteria was met via combination of; (1) strips of neoprene rubber inserted (with some difficulty), between the top of each module and the bottom of the support for the next higher module, (2) rubber weather strips contacting the bottom of each module at the innermost edge of its support strips; (3) neoprene rubber tubing stretched around

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the sides of each module which contacted the interior wall of the MH, and (4) a 2' x 4' x 1" thick rubber mat covering the interior surface of the SAMFU door. When bolted in place the door effectively sealed the fourth side of the module, the support strips, and the sides, top, and bottom of the SAMFU.

III. PROCEDURES

A. SAMPLING

1. PRODUCT WATER

Grab samples of SAMFU product water were taken for suspended solids, turbidity and media loss evaluation by filling one quart glass container from the SAMFU discharge hose.

2. RAW WATER FEED

Grab samples of concentrated and dilute raw water feed were taken by opening a one quart glass container 12" below the surface of the thoroughly mixed feed. Exactly 250 ml of the grab sample from each 31 gallon batch of diluted feed pumped to the SAMFU was used to create a "composite" sample for suspended solids and turbidity analysis.

B. ANALYSES MEASUREMENTS AND CALCULATIONS

1. SUSPENDED SOLIDS

Suspended solids of SAMFU raw water feed and product water determined according to the procedure described in the 16th edition of Standard Methods.*

2. TURBIDITY

Turbidity of SAMFU raw water feed and product water were determined according to the nephlometric method described in Standard Methods.** A HACH 2100-A turbidimeter was used to read results in nephlometric turbidity units (NTU's). Instrument sensitivity is 1.0 NTU over the 0 - 40 NTU range.

* Method #209C; pg.96 for Suspended Solids
** Method #214A; pg.134 for Turbidity (NTU)

3. TEMPERATURE

A dry bulb mercury thermometer was used to periodi-
cally read raw water feed and product water temperatures in
farenheit degrees

4. PRESSURE

Pressure above and below each of the modules stacked
within the MH was measured by direct reading of 30
psi in line gages.

5. FLOW

The time necessary to fill a precalibrated two (2)
gallon container with product water from the SAMFU was
used to calculate flow through the SAMFU via:

$$Q \text{ (GPM)} = \frac{2 \text{ gal}}{X \text{ sec}} \times \frac{60 \text{ sec}}{1 \text{ min}}$$

where: Q = flow
X = time required to fill 2 gal

6. HYDRAULIC LOADING

$$H.L. \frac{GPM}{SQFT} = \frac{Q \text{ (GPM)}}{S.A. \text{ of media}^*}$$

where: H.L. = hydraulic loading
Q = flow
S.A. = surface area

* one module only
** Hydraulic loading decreases with run time

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7. SOLIDS LOADING

This measure of total amount of solids applied to media volume as given by:

$$SL \frac{lbs}{cuft, media} = \frac{Q \; (GPM)t(min) \; x \; SS \; (ppm) \; x \; 8.34 \; (lb/gal)}{MV \; (cuft)}$$

where: SL = solids loading
SS = suspended solids
Q = flow
MV = media volume
t = run time

C. EVALUATION (TEST) PROCEDURES

1. MEDIA LOSS EVALUATION

a) Filtration Mode:

All product water discharge from the SAMFU was passed through a 0.018" mesh screen. One liter unscreened, aliquots at time 0, 2, and 5 minutes were examined visually for obvious loss of anthracite. An estimate of the particles resembling filter media was made and reported as particles per liter. Visual observation was reinforced by observation of residue on filtration of several samples through Whatman #40 filter paper.

b) Backwash Mode:

Backwash of the modules was attempted both within the MH, and externally to the MH by inverting individual modules and applying hose pressure to the underside of the media.

Media loss from backwash in-situ was observed by reverse flow "clean"(prior to raw water filtration) and "dirty"(after use to filter raw water feed) modules. Flow through the SAMFU was reversed and discharge passed through a 0.081" mesh white plastic screen. Because the black anthracite is the least dense media it would be expected to "float" out of the MH with backwash, if the screens were not functioning as designed. Therefore, the screen was examined for presence of particles resembling the anthracite.

Media loss in external backwash was observed for both "clean" and "dirty" modules by passing all discharge

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flow through a 0.081" mesh white plastic screen; and filtration of one liter aliquots of backwash from "clean" module through #40 filter paper. Particles visible to the eye, and resembling anthracite media were estimated and reported as "particles per liter"

2. VALVE RELEASE EVALUATION PROCEDURE

A release pressure test device was designed and constructed from a 12" length of 2" diameter PVC pipe, fitted with hose connection and an inline 30 psi gage. This device was used to determine release pressure of the module by-pass valve prior to insertion in the module.

The valve to be tested was affixed to one end of the pipe and water flow into the pipe was begun. Pressure buildup was reflected in the gage. The pressure at which the valve opened to allow water flow out of the pipe was observed and adjusted, if necessary, to 4.0 psi. Valves in series opened at pressure differential of 4.0 psig across the valves. See figure 15.

Observation of any substantial pressure differential across the valve, at approximately 4.0 psig, during actual filtration runs was taken as indicative of valve functioning.

Observation of pressure across the modules was made on 30 psi gages installed on the MH. One gage (No. 1) was a 100 psi gage.

3. SOLIDS REMOVAL EVALUATION

Composite samples ,(250 ml of each batch), of raw water feed and periodic one liter grab samples of product water from the SAMFU were analyzed for suspended solids and turbidity. These data were analyzed and plotted to show removal trend, extent, and efficiency.
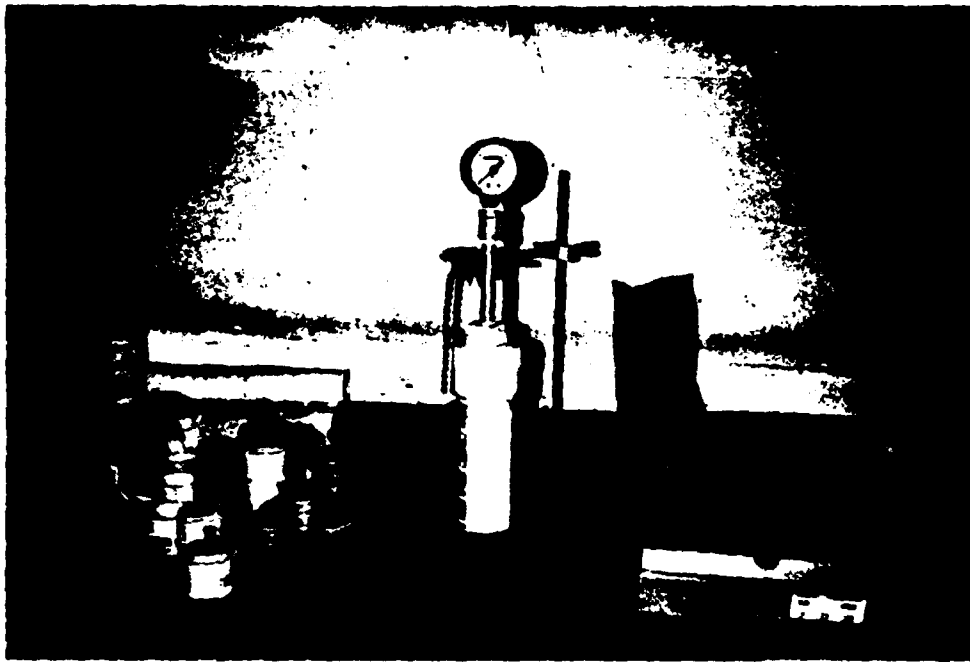
13

FIGURE 15
VALVE TESTER

IV. RESULTS AND DISCUSSION

Conventional filters may clog well in advance of full utilization of filter capacity, due to influx of solids, or a particular fraction thereof such as colloidals.

The size specific modules and by-pass valve design of the SAMFU holds promise of "full" utilization of media capacity within a module and exposure of additional capacity as a preceding module becomes clogged. Thus by presenting a number of filters in series to the offending particle fraction, it promotes their removal and prolongs filter runs.

The objectives of this AERINC study were:

A) Determine feasibility of using screens to prevent media loss during filtration and backwash

B) Determine the feasibility of using shallow depth, modular anthracite filters for solids removal

C) Determine the feasibility of using valves to by-pass modules, based on pressure sensed

This section presents results and discussion for ten (10) trial runs directed toward these goals. Runs 1-8 focused on testing system components and structural integrity to define limits.

Raw water feed as high as 5000 ppm solids was used primarily to help visualize the process occurring in the unit. The unit was also fed tap water at 8 psi to test integrity of module and housing under pressure. This testing resulted in improved module seals and by-pass prevention, and the use of an external, vise like, device to help strengthen door seal as pressure increased.

Runs 8, 9, and 10, the latter of which successfully demonstrated SAMFU potential on August 18,1986, focused on (1) turbidity/ solids removal and (2) pressure profiles as related to valve opening and its effect on solids removal efficiency. Consequently these trials are the focus of this section.

Removal of the SAMFU door after filtration trials permitted observation of the modules and insight to the process that took place. Tops, (wood covers), of some modules were observed to be uniformly covered with solids to depths

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up to 0.75". Mud was evenly distributed over media, often to depths of up to 0.5". Figures 16: show solids deposition after run 9, (940 mg/l solids feed for 2.5 hrs). These figures qualitatively and graphically demonstrate solids removal capability of the modular units. The following consideration of the several study objectives attempts to quantify these results.

A. OBJECTIVE ONE

Determine the feasibility of using screens to contain media within "modules" without significant loss in filtration or backwash modes.

Evaluation of media loss was accomplished for both filtration and external backwash modes, using clean modules. Estimation of media loss from dirty modules proved unproductive because of the difficulty in visually distinguishing media particles on either screens or Whatman filters. Since maximum potential for media loss is presented by external backwash, no effort was made to perfect this aspect of the study.

The 0.018" mesh capture screens showed no visible evidence of media loss from clean modules, even on external (hose pressure) backwash. The possibility of particle fracture to size smaller than 0.45 mm and passing through the capture screen, was therefore investigated. The aliquots of the external backwash taken at time zero (0), and within the 3-5 minute backwash period were filtered through Whatman #40 filter paper. Examination of the paper after filtration showed no significant media loss. Examination of the fiberglass filters used to determine suspended solids corroborated this finding.

It remains to identify specific media size and capacity needed to be installed in future modules; and the mesh screen required to hold that media in place. Once defined, the appropriate materials must be located or fabricated before efficiency testing may begin.

B. OBJECTIVE No. 2

Evaluate suspended solids and turbidity removal of the SAMFU.

Turbidity and solids removal through the SAMFU was evaluated in runs 9 and 10. A composite sample of raw water feed, and periodic grab samples of product water were tested for suspended solids and turbidity, these data were plotted as a common coordinate against time, to demonstrate removal trends. These data are shown in figures 17 and 18

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FIGURE 16
SOLIDS
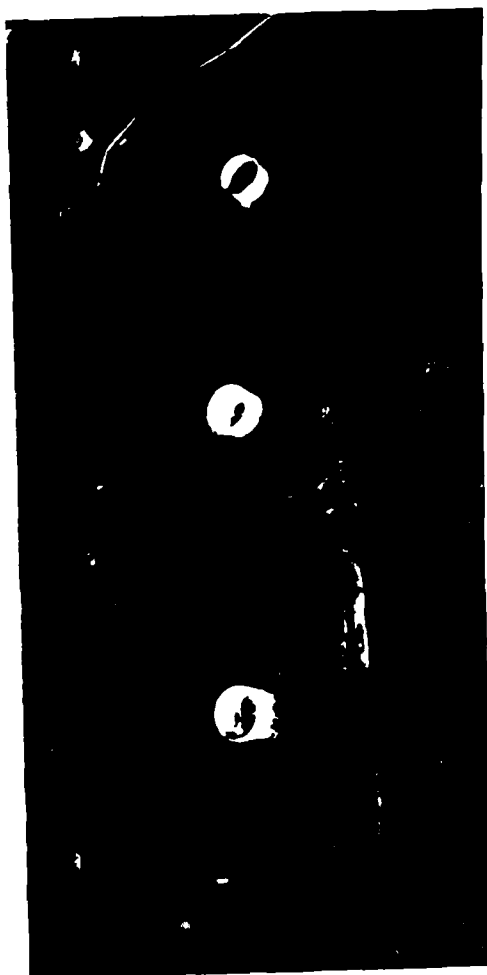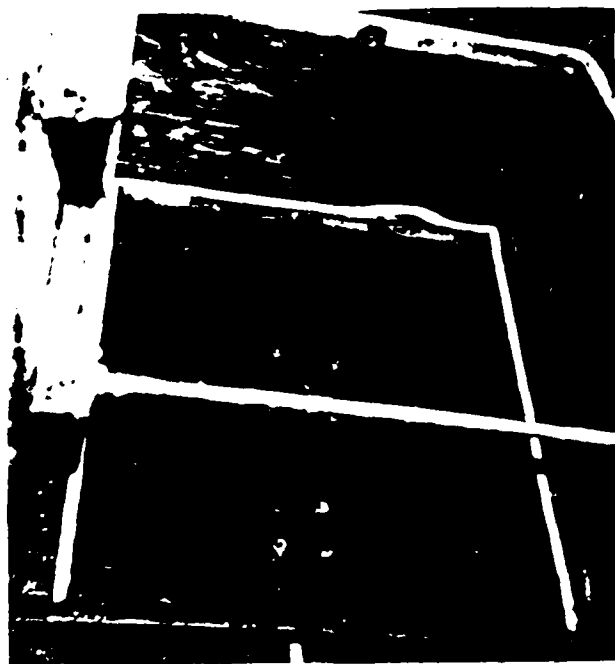
FIGURE 17

SOLIDS TURBIDITY REMOVAL RUN #9

FEED WATER 940 TSS: 150 NTU

□ EFFLUENT TSS   + EFFLUENT NTU
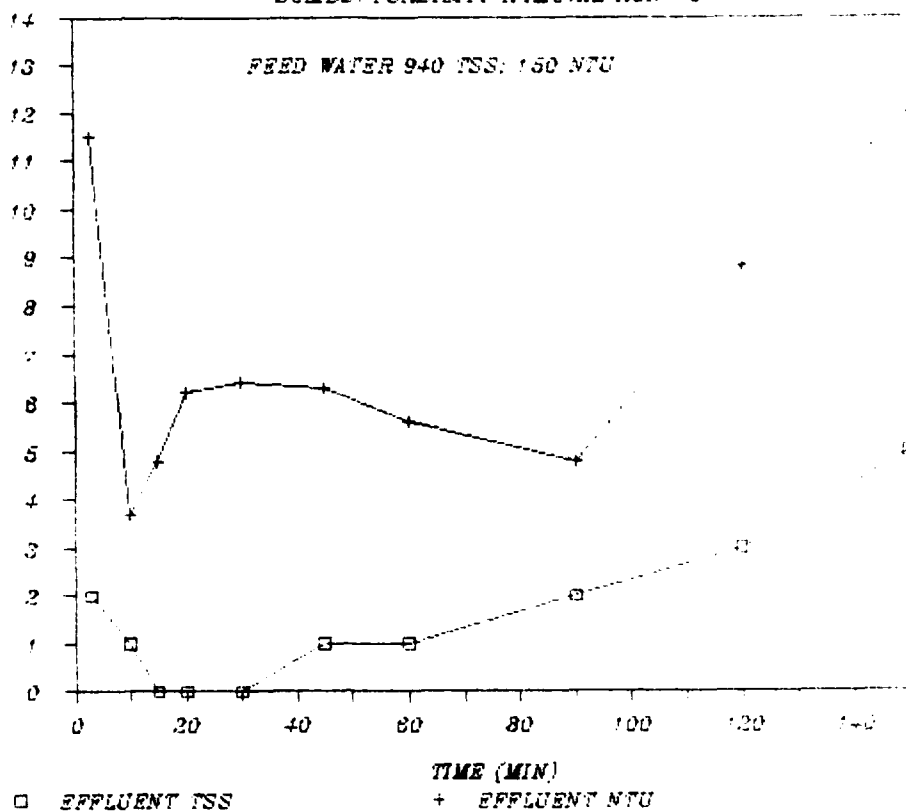
FIGURE 18

SOLIDS & TURBIDITY REMOVAL - RUN 10

FEED=1480ppm & SS=100 NTU

□ EFFLUENT TSS   + EFFLUENT NTU
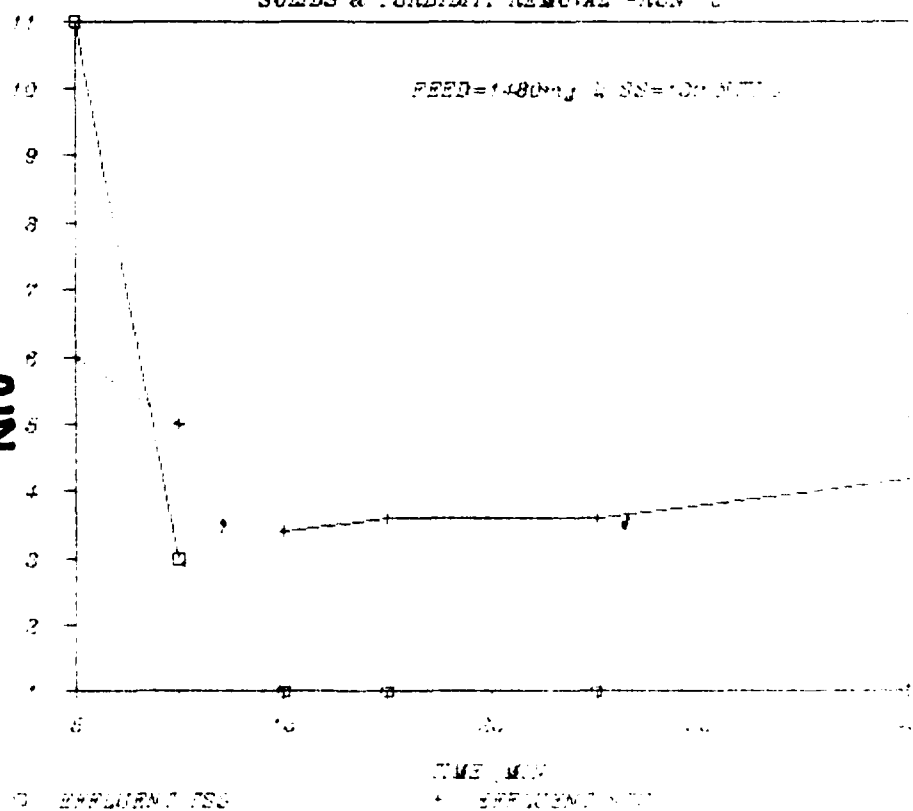
In run nine raw water flow through the SAMFU was 4.6 gpm diminished gradually with run time and solids buildup. Hydraulic loading on the 1.11 sqft. media surface in each module was 4.0 gpm/sqft, raw water turbidity was 150 NTU's. Raw water suspended solids (TSS) was 940 mg/l. Under these conditions the SAMFU unit described in section II-D above affected greater than 99% removal of suspended solids and 92% removal of turbidity, within two minutes of initializing the run. Further, it sustained these removal percentages for more than a two (2) hour time. Run was arbitrarily stopped at 2.5 hours, after some deterioration of solids content occurred.

In run ten raw water flow and loadings for this "demonstration" run were 4.6 gpm, and 4.0 gpm/sqft respectively. Turbidity was 130 NTU; suspended solids was 1480 mg/l.

Under these conditions the SAMFU, described in section II-D above, once again affected greater than 99% removal of suspended solids and 95% turbidity removal. These efficiencies were sustained for the 45 minute run. Turbidity values ranged from 3.4 - 6.0 during this period.

Deterioration of product water quality is attributed to (1) inadequate capacity in a crucial (lower) module, (2) structural problems in the unit, such as gasket leaks permitting unwanted by-pass of the media, (3) inappropriate pressure, capacity design.

All of these will be investigated and rectified in future development

During this period suspended solids were less than 5 mg/l and turbidity was less than 12 NTU.

Figure 19 plots SAMFU solids and turbidity removal efficiency as a function of time, demonstrating its ability to sustain removal efficiency.

Runs 9 and 10 both demonstrate that the modular SAMFU is capable of effectively reducing solids and turbidity of high solids content "synthetic" raw water feed. It can sustain this removal efficiency for two (2) hours or more.

Solids removal is affected by filtration through shallow beds of variously sized anthracite media, followed by sand modules. A valving system is provided to by-pass any module which has become so encrusted as to inhibit throughout and shorten run times. Valve release was dependent on development of pressure differential of 4 psig across the valve, allowing opportunity for utilization of filter capacity before release. As this pressure differential was not achieved before product turbidity showed increasing trend, it is apparent that while the concept is clearly applicab-

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FIGURE 13

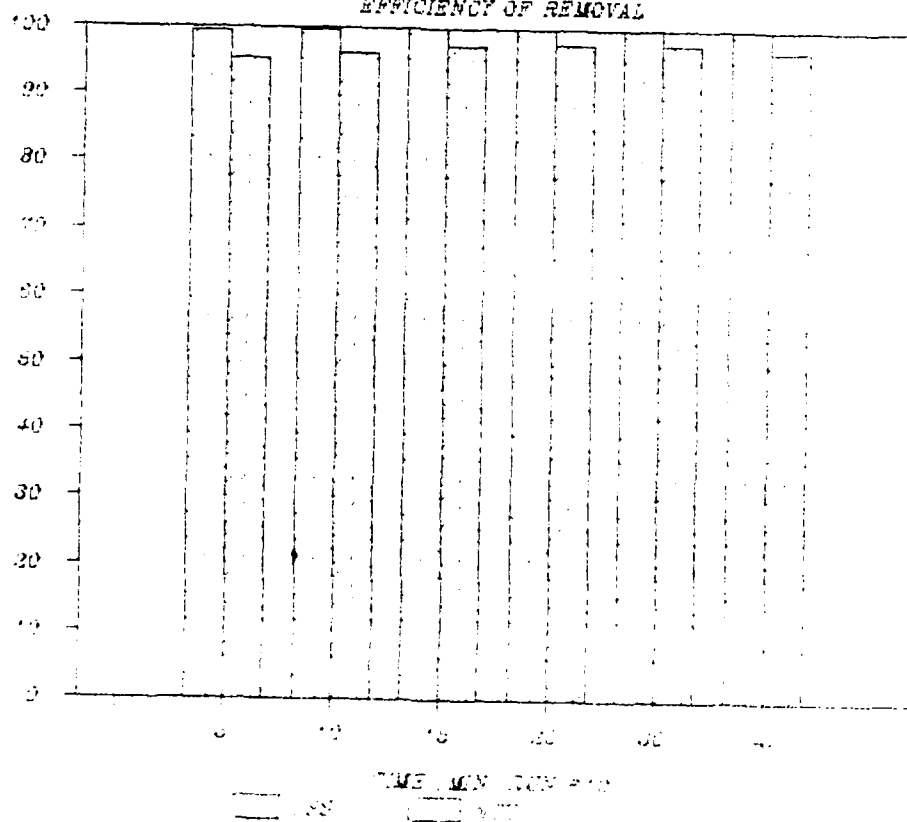## EFFICIENCY OF REMOVAL

%REMOVAL

TIME (MIN) RUN #9

□ TSS   □ NTU

EFFICIENCY OF REMOVAL

%REMOVAL

TIME (MIN) RUN #10
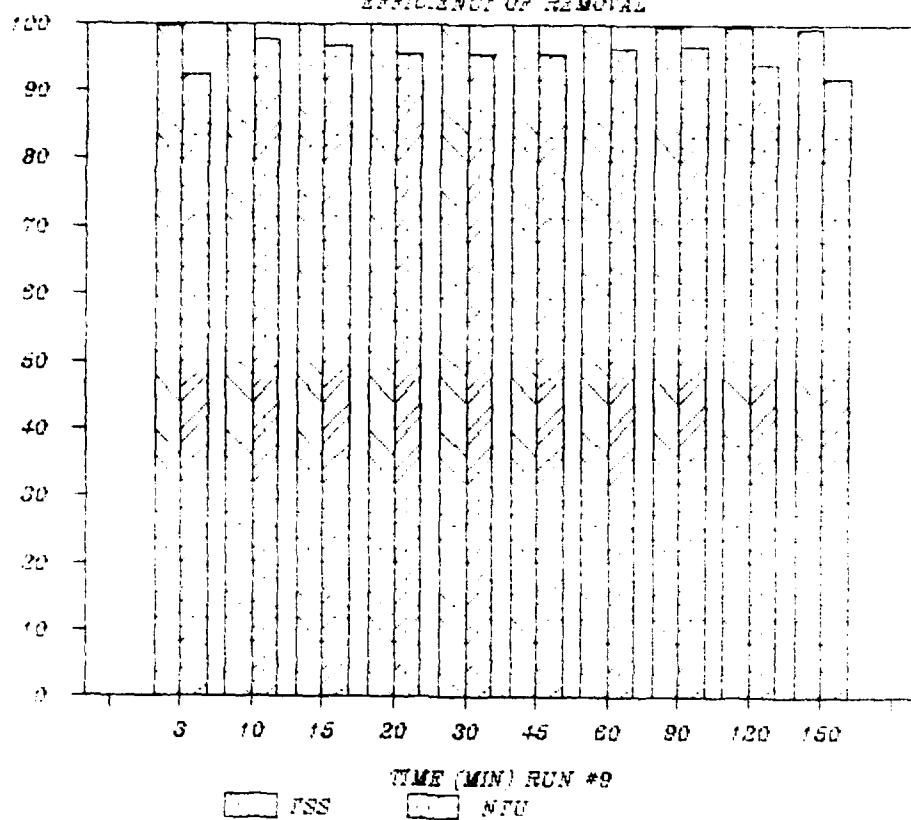
le, work is needed to balance filter capacity and valve release pressure. Such balance shows remarkable promise in light of these successes using media size and module concept only.

It remains to evaluate effectiveness under different flow and load conditions and types of solids; and to provide conditions to adequately test the valve pressure, capacity concept.

C. **OBJECTIVE No. 3**

Determine feasibility of using valves to by-pass modules

1. Concept

As solids began to cover the surface and fill the pore openings of a particle media, a resistance to the flow of water through that media develops. This resistance to the force of the pump trying to push the water through the media results in a buildup of pressure above the surface of that media (upstream). This pressure results in termination of the filtration operation in conventional filters. In the SAMFU, when this pressure approximates the by-pass valve release pressure, the valve opens effectively removing the clogged media from service.

The advantages to the valves opening based on a pressure differential included:

a. No modules would be by-passed unless the pressure buildup were a result of solids accumulation within that particular module, and not a result of accumulating solids in several modules. Keeping all modules in service would result in increased total filter run times and improved effluent quality.

b. A single failed module would be by-passed if the pressure differential across that module were reached permitting continued operation and lengthening run times.

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2. PRESSURE DATA EVALUATION

The establishment of solids buildup and pressure at a lower (downstream) module dictates the minimum pressure at modules above it (upstream). Consequently, pressure readings should remain constant or decrease in the downstream direction. Pressure at any given gage, (module), should increase gradually as solids collect.

The raw pressure data for runs 8 and 9 shows a trend to initial pressure buildup in the upstream modules with gradual spread and increase in lower modules, as the filter run progressed. Occasionally, a downstream module showed higher pressure than the one above it, or a specific gage (module) showed a decrease of pressure with time. These deviations from expectations are noted and attributed to:

1. Module Housing leaks
2. gasket leaks
3. using the lowest 10% of gage range for readings

Pressure data for runs 8 and 9 are shown in figures 20 and 21 respectively.

In run number 8, gages 0, 1, 2, 4, and 6 all show a gradual and consistent increase in pressure throughout the run. Gage 3 however shows pressure fluctuations, and both 3 and 2 show readings lower than gage 4, indicating perhaps a release of pressure here due to vessel leakage. This was, in fact, where excessive leakage problems occurred around the door gasket, and the external vise was fashioned to minimize leakage for subsequent filtration runs. Gage 5 shows a gradual increase in pressure up to 1.0 psig and then a decrease in pressure to 0.5 psig. In this case, the internal gaskets around module no. 6 failed during the run, resulting in the pressure drop noted and deterioration of effluent quality. It appears that the pressure differential between gages 1 and 2 was approaching that required to open the module by-pass valve in module 2. The pressure readings for gage 2, however, is highly suspect, and we do not feel that any of the module by-pass valves opened during this filtration run.

In run #9, it is noted that pressures on all gages gradually increase during the run. With the exception of gage zero (0) and the last four readings of gage 4, all pressure readings also remain constant or decrease in the downstream direction. Gage zero was a 0 100 psig span gage and all readings from it are rough estimates. There was some leakage in the area of gage #4 which may have affected these last readings or the gage itself may have malfunctioned.

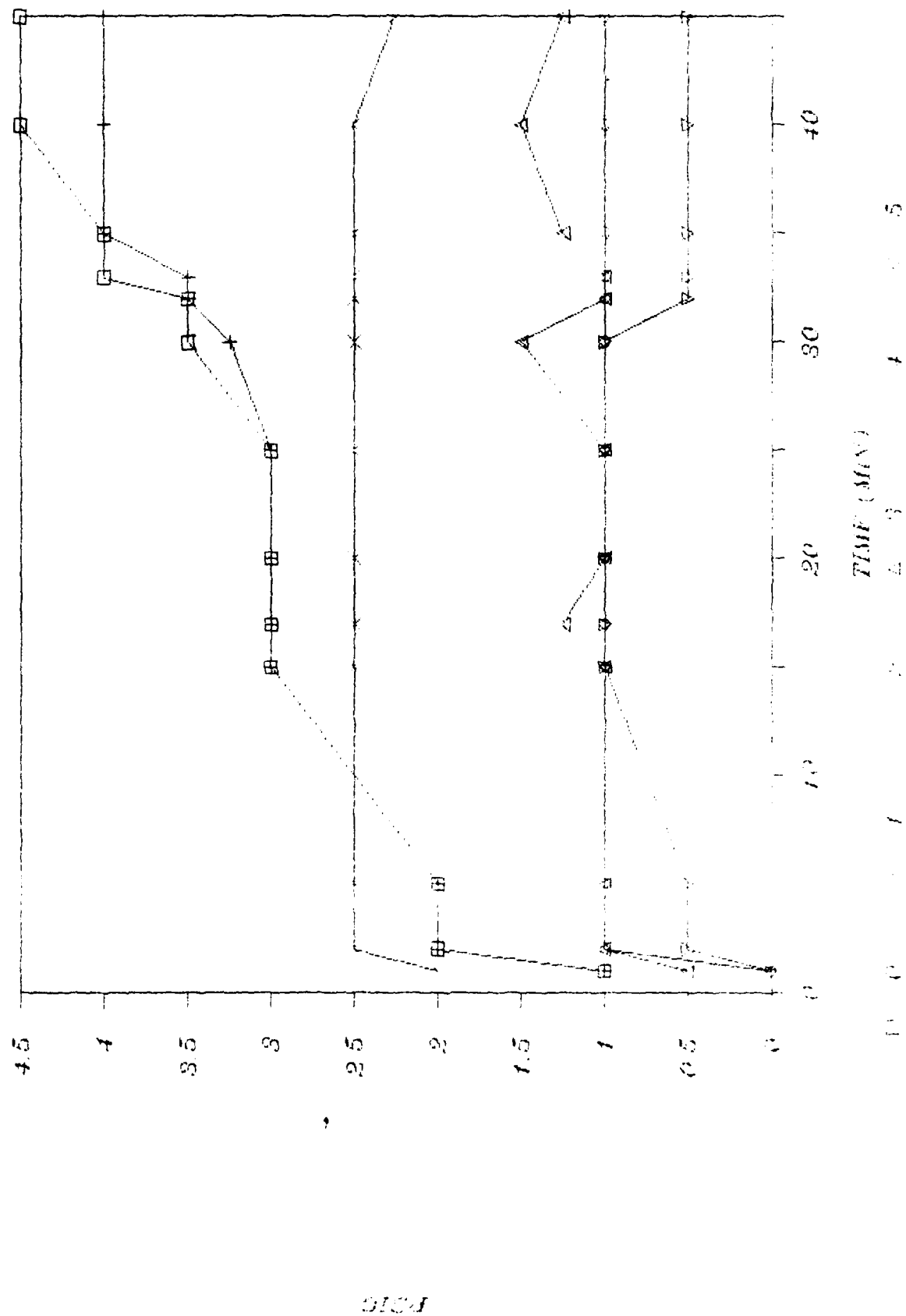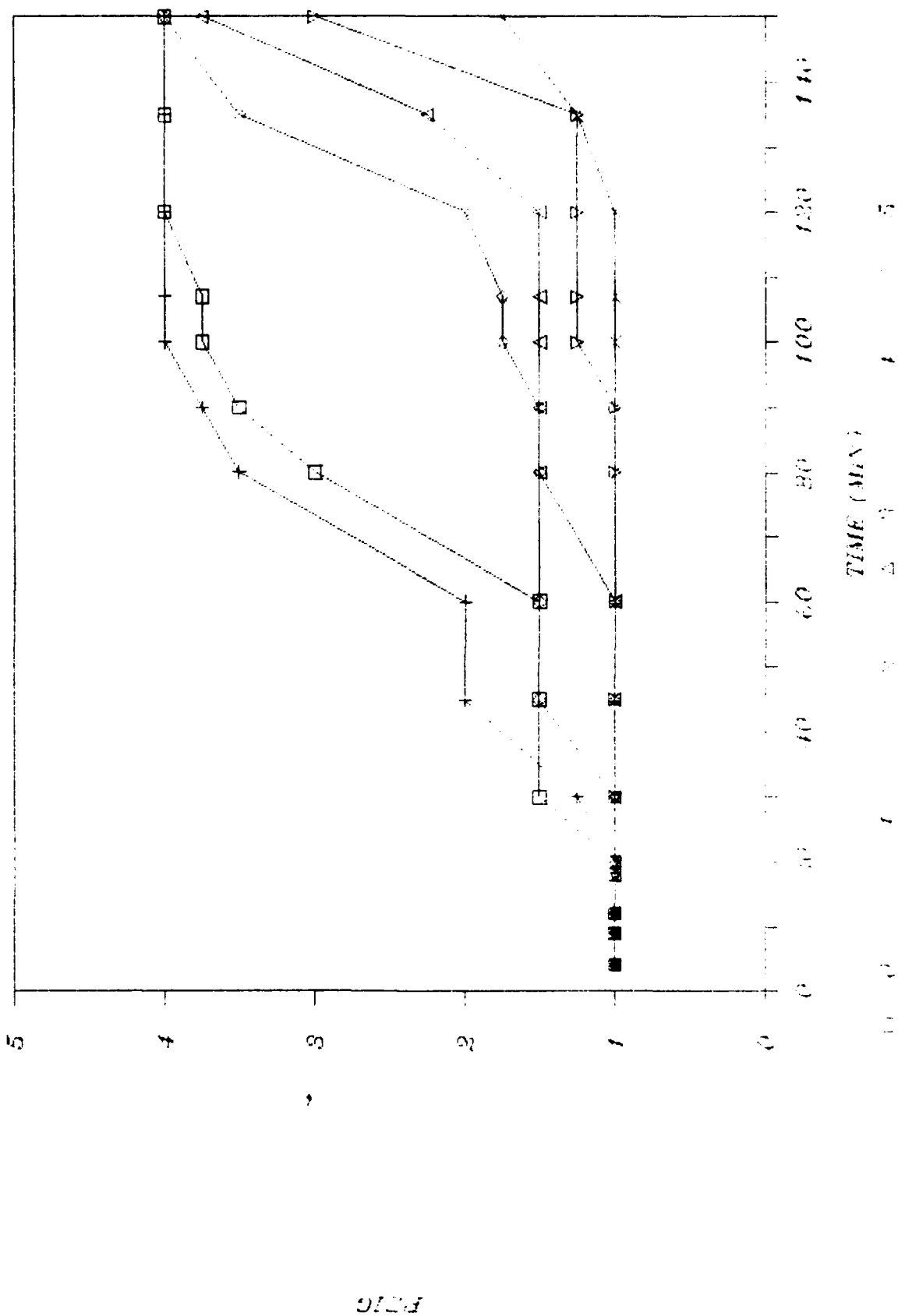PRESSURE DATA RUN #8

TIME (MIN)

FIGURE 20

FIGURE 21

PRESSURE DATA RUN #9

LISTED BY GAGE NUMBER

To determine whether any of the module by-pass valves opened during this filtration run, the pressure differential across each valve must be examined. Table BB presents pressure differential data across each module during run 9.

TABLE BB
RUN #9: PRESSURE DIFFERENTIALS

MODULE	30	45	60	75	90	105	120	135	150
			TIME (15 min intervals)						
1	.25	*	*	*	*	*	*	*	*
2	.25	.50	.50	2.0	2.25	2.25	2.0	.50	0.0
3		.50	.50	0.0	0.0	0.25	0.5	1.25	.25
4				0.5	0.5	*	*	*	*
5						0.25	0.25	1.0	.75
6						0.25	0.25	.25	2.0

* only data available is invalid

The greatest pressure differential recorded was 2.25 psig, or less than the 4.0 psig required to open the by-pass valves. It is therefore concluded that no by-pass valves opened during this run.

The pressure differential readings are also an indication of where filtration has occurred, for it is the build-up of filtered solids that causes this pressure differential. A low pressure differential does not indicate that filtration is not occurring, but possibly that enough solids have not accumulated to cause an increase in pressure or that filtration and resultant pressure in a module downstream is masking the filtration occurring in that particular module.

This data in Table BB shows a general trend to increasing pressure differentials in the downstream direction, as the filtration run progresses. After 30 minutes only modules 1 and 2 show a differential, after 75 minutes, modules 1 through 4 potentially show a differential, and after 105 minutes all modules have some potential pressure differential. This indicates that the entire depth of the filter (all modules) are actively filtering solids. However, the larger media (first modules) are becoming clogged

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first. In order to maximize filter run time and removal efficiencies an 'ideal modular filter' for an ideal parti- cular raw water source,(ie. uniform particle size distribu- tion), solids would accumulate simultaneously throughout the depth of the filter. This would result in gradual and equal increase of pressure differentials (loss of head) across each module. Further testing with more sensitive equipment is warranted to investigate the relationship of media size, pressure, particle size distribution and solids removal efficiency. For we believe it would be extremely valuable in evaluation and subsequent maximization of SAMFU efficiency through proper media type, size, and depth sele- ction. Pressure data will help to design the modules and housing for future SAMFU's.

V. CONCLUSIONS

The data presented above support the following conclu- sions.

1. The SAMFU has been demonstrated and efficiently removes solids and turbidity from the raw water feed.

2. Fixed media within modules will permit SAMFU use in various spatial orientation and configuration. This holds promise for reduction of space require- ments, or at least better utilization of available space in future ROWPU's.

3. Additional effort is required to develop SAMFU potential for:

a) Full use of media capacity by striking balance between operating pressures,media sizing, capacity and raw water particle sizes.

b) External filtration runs via 3a above, or the use of valves to effectively remove clogged modules from service.

4. Anthracite is an effective alternative for some sand media which holds promise for weight reduc- tion.

5. Screens, without media, will capture suspended so lids and hold promise of use as a prescreen "media"

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of minimum mass.

6. Full use of filtration media depth is indicated as feasible and holds promise for extension of filter run time. This compromise between capacity and volume requirement;pressure and media size requires much better definition.

7. Screens if properly matched to media size, hold promise for use to hold the media in a fixed position within the modules. Additional work is needed to identify sources, materials, and to match media to screen mesh for smaller particle sizes.

8. Use of properly sized screens to hold media will minimize, possibly eliminate media loss in either filtration or backwash mode. Work is needed to affect "in situ" backwash of the modules.

9. Release pressures for by-pass valves were not reached in this preliminary study. This desirable feature remains to be established and studied.

VI. RECOMMENDATIONS

AERINC is pleased to have had the opportunity to conduct this preliminary study of its modular concept filter. Based on the results and experience derived from this effort, we recommend that:

A. The Belvior Army Research Development and Engineering Center continue its support of AERINC's studies of the SAMFU and its feed systems. A condensed outline of the work to be completed in further study is summarized below:

1. Continuation of preliminary testing to define additional design parameters for a second generation SAMFU II model.

2. Design and fabricate SAMFU II as a test unit that will:

2. Design and fabricate SAMFU II as a test unit that will:

    a. Permit operation at higher pressures

    b. Allow flexibility in media depth (capacity); and type

    c. Eliminate leaks and raw water by-pass of filtration media except via by-pass valves

    d. Reflect operation/maintenance requirements

    e. Allow for in situ backwash, without loss of media

    f. Reflect compatibility requirement for ROWPU 600, for future ROWPU units; and additional SAMFU units

3. Test this redesigned model

    a. In various operational modes, ie. filtration, backwash, up flow, down flow, horizontal flow

    b. At pressures which permit evaluation of by-pass valves

    c. With naturally occurring raw water supply

    d. With various light, high surface area media

4. Evaluate

    a. Media loss from backwash/filtration

    b. Product water production rate and quality as related to:

        operating pressure
        by-pass via valves
        media capacity

    c. Ability of this SAMFU to produce potable water when operated in conjunction with various disinfection alternatives

5. Redesign and fabricate SAMFU III to reflect experience and to assure reductions in weight, better utilization of available space, continuous filtration mode.

B. That the appropriate BRDEC personnel meet with AERINC to discuss progress and provide input to prioritization of our effort past and potential.

C. Consider the use of Cost Plus Fixed Fee contract to

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assure continuity of AERINC effort to provide a SAMFU that will operate independently or in consort with other components of the ROWPU 600 (or future ROWPU).

Respectfully submitted: Sept 29, 1986

RONALD McILLWHIN. PRES
HERINC.

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END

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